Chapter 2

1. Introduction

There are two major collider experiments at Fermi National Laboratories: D0, named after position in the Tevatron, and CDF, short for Collider Detector at Fermilab. Both experiments are large, multifaceted detectors designed to measure and probe much of the same physics. This dissertation uses data collected from CDF. This chapter will describe in some detail the Tevatron and the CDF detector.

1.1 The Tevatron

The Tevatron is the hadron collider located in Batavia, IL at Fermi National Labs. It collides beams of protons and anti-protons at a center-of-momentum energy of 1.96GeV. It capable of producing most of the particles described in the standard model including the top quark.

The beams begin in the Cockcroft-Walton generator, which negatively ionizes hydrogen gas, and exposes the ions to an electric field to accelerate them up to 750keV. Next, the ionized gas is passed into a 150m long linear accelerator called the Linac. There, it is accelerated up to 400MeV. At this point, the hydrogen is passed through a carbon foil, which strips away the electrons, leaving only the nuclei to be passed into the Booster. The Booster is a small ring accelerator that accelerates the protons - the hydrogen nuclei - up to 8GeV. Once this energy is obtained, the protons are transfered to the Main Injector. The Main Injector has many functions, one of which is to accelerate the protons up to an energy of 150GeV and inject them into the Tevatron. Another job of the Main Injector is to accelerate protons up to 120GeV for anti-proton production. This is done by sending protons to a nickel target. Colliding protons with a nickel target will produce many types of secondary particles, some of which will be anti-protons. The anti-protons are sent into a storage ring where they are accumulated and cooled through a process called stochastic cooling. After sufficient anti-protons are collected, they are sent to the Recycler where they undergo additional cooling, and are stored in preparation for injection into the Tevatron. Each time the production of protons or anti-protons is completed, a bunch is created. The process is repeated thirty-six times to create thirty-six proton bunches and thirty-six anti-proton bunches. Once all of the bunches are created, they are loaded into

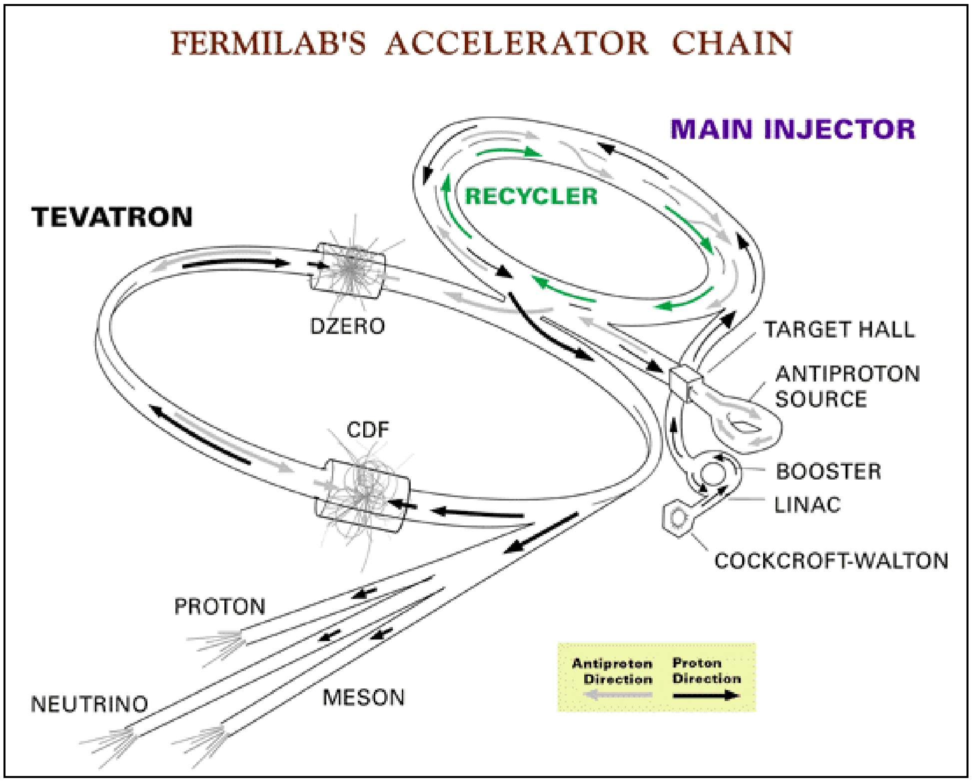

Figure 1: Graphical representation of proton and anti-proton beams at Fermilab

the Tevatron. The proton and anti-proton beams travel in the same beam line, but in opposite directions. After the Tevatron is fully loaded, the beams are accelerated up to an energy of 980GeV. The beams are then allowed to collide at two positions in the Tevatron, D0 and B0, the positions of the D0 and CDF detectors respectively.

Producing anti-protons is a difficult process. The luminosity of the Tevatron depends on both the number of protons in the beam and the number of anti-protons. The number of anti-protons is typically the limiting factor. In order to keep a high luminosity, instead of sending the anti-proton beam to a beam dump at the end of a store, it is sent back to the Recycler where it joins newly produced anti-protons.

1.2 The Collider Detector at Fermilab

The detector is comprised of many subsystems, each of which is its own type of particle detector. At the center of the detector is the silicon vertex detector (SVXII). The purpose of

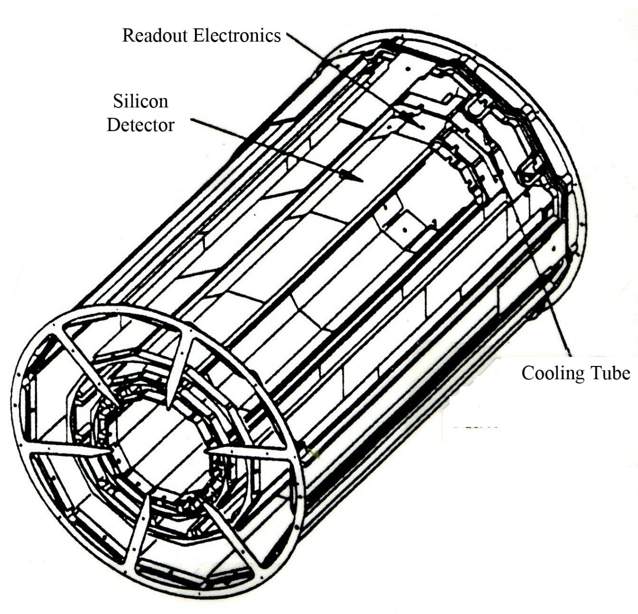

Figure 2: One barrel of the SVXII

the SVXII is to provide accurate micro-vertex detection. It is comprised of three cylindrical barrels of double sided silicon microstrip detectors. Each barrel has five layers, with each layer made up of twelve "ladders". The "ladders" are the low mass substrates that support the silicon crystals. The SVXII is 96cm long and covers approximately 2.5σ of the luminous region.

Outside of the SVXII are the intermediate silicon layers (ISL). The ISL has 5 layers, one for the central region and two for each plug region. Similar to the SVXII, the layers of the ISL are organized into "ladders", except that instead of two crystals per ladder, the ISL has three. Together, the SVXII and ISL cover a range of $|\eta| \leq 2.0$ and provide standalone tracking and b-tagging in that region.

While it is not located at the very center, the heart of the detector is the Central Outer Tracker (COT). It is an open cell drift chamber. The COT and the silicon detectors are surrounded by a superconducting solenoid that produces a 1.4T magnetic field parallel to the beam axis. The COT is the third part of CDF's tracking system. It provides tracking of particles in the region $|\eta| \leq 1.0$. The COT is broken down into four axial and four stereo superlayers. The number of cells in each superlayer depends on the radius of the superlayer, the innermost having one hundred sixty-eight cells and the outermost having four hundred

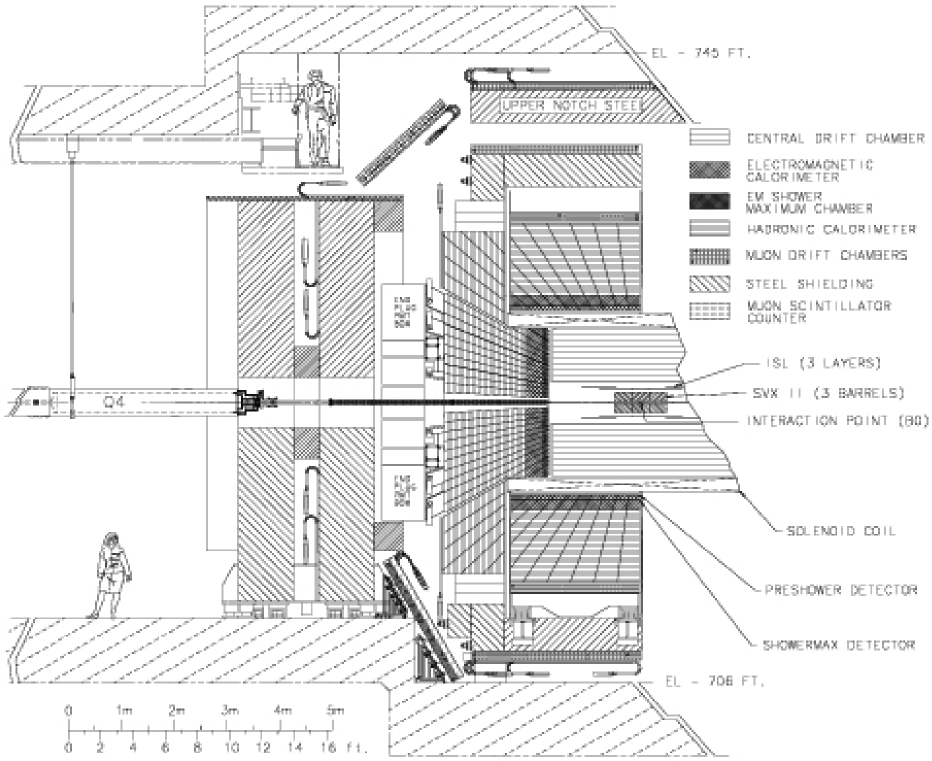

Figure 3: Cross-section of the collider detector at Fermilab

eighty. Each cell has twelve sense wires. As charged particles pass though the COT, the gas inside is ionized and begins to drift toward the sense wires. After a charged particle has passed through many cells, its path can be tracked.

Outside of the tracking systems are the calorimeters. There are two types of calorimeters in the detector: the inner is the electromagnetic (EM) calorimeter and the outer is the hadronic calorimeter. The EM calorimeter is made of twenty-three layers of lead and scintillator. Each layer is comprised of 4.5mm lead and 4mm scintillator. There is an embedded two-dimensional readout strip chamber at shower maximum. The EM calorimeter is read out with photomultiplier tubes. The hadronic calorimeter also has twenty-three layers, but is made of iron and scintillator. The iron in each layer is 50mm thick, and the scintillator is 6mm thick. Together, the central and plug calorimeters cover a range of $|\eta| \leq 3.0$. The calorimetry is segmented into towers that radiate outward from the optimal collision point.

The outer part of the detector is the muon detection system. There are four parts to this system: the Central Muon System (CMU), the Central Muon Upgrade (CMP), the Central Muon Extension (CMX), and the Intermediate Muon System (IMU). Each of these systems is a combination of drift tube detectors and scintillator detectors, except for the CMU which is only a drift tube detector. The CMU and CMP cover the same range, $|\eta| \leq 0.6$, while the CMX covers $0.6 \leq |\eta| \leq 1.0$ and the IMU covers $1.0 \leq |\eta| \leq 1.5$.

1.3 Event Triggering

Given the large number of channels, cells, layers, wires, and PMTs that make up the detector, there is a enormous amount of data from each event. This is further compounded by the 7.6Mhz crossing rate of the Tevatron. This massive data rate is made manageable through the CDF triggering system. There are three levels of triggering that help decide which events have interesting physics in them, and if so move their data to permanent storage.

The Level 1 trigger is a storage pipeline that can store the data for forty-two beam crossings. The Level 1 decision is made on the calorimeter, central tracking chamber, and the muon detector data. The Level 1 trigger has $4\mu s$ to make a decision on an event as it moves through the pipeline, and is done synchronously with the data in the pipeline. If an event is deemed interesting, it is passed to the Level 2 buffer. The acceptance rate for the Level 1 trigger is designed to be less than 50kHz.

There are four Level 2 buffers. Once an event is loaded into a buffer from the Level 1 accept, that buffer can not be used again until the Level 2 decision is made. If all four of the buffers become filled, then any new events accepted by the Level 1 trigger will be lost and the experiment will incur deadtime. The data from the silicon tracking system, the central tracking chamber, the calorimetry, and the muon detectors is used to make the Level 2 decision. The average decision time for Level 2 is $20\mu s$ and has an acceptance rate of about 300Hz. Together Level 1 and Level 2 accept about one in twenty-thousand events.

Once an event has been accepted by the Level 2 trigger, it is passed to the DAQ buffers, where it waits to be sent to the Level 3 computer farm via a network switch. Each event has all of its data assembled for analysis. After it has been analyzed and accepted, it is written to permanent storage. The Level 3 acceptance rate is about 75Hz.

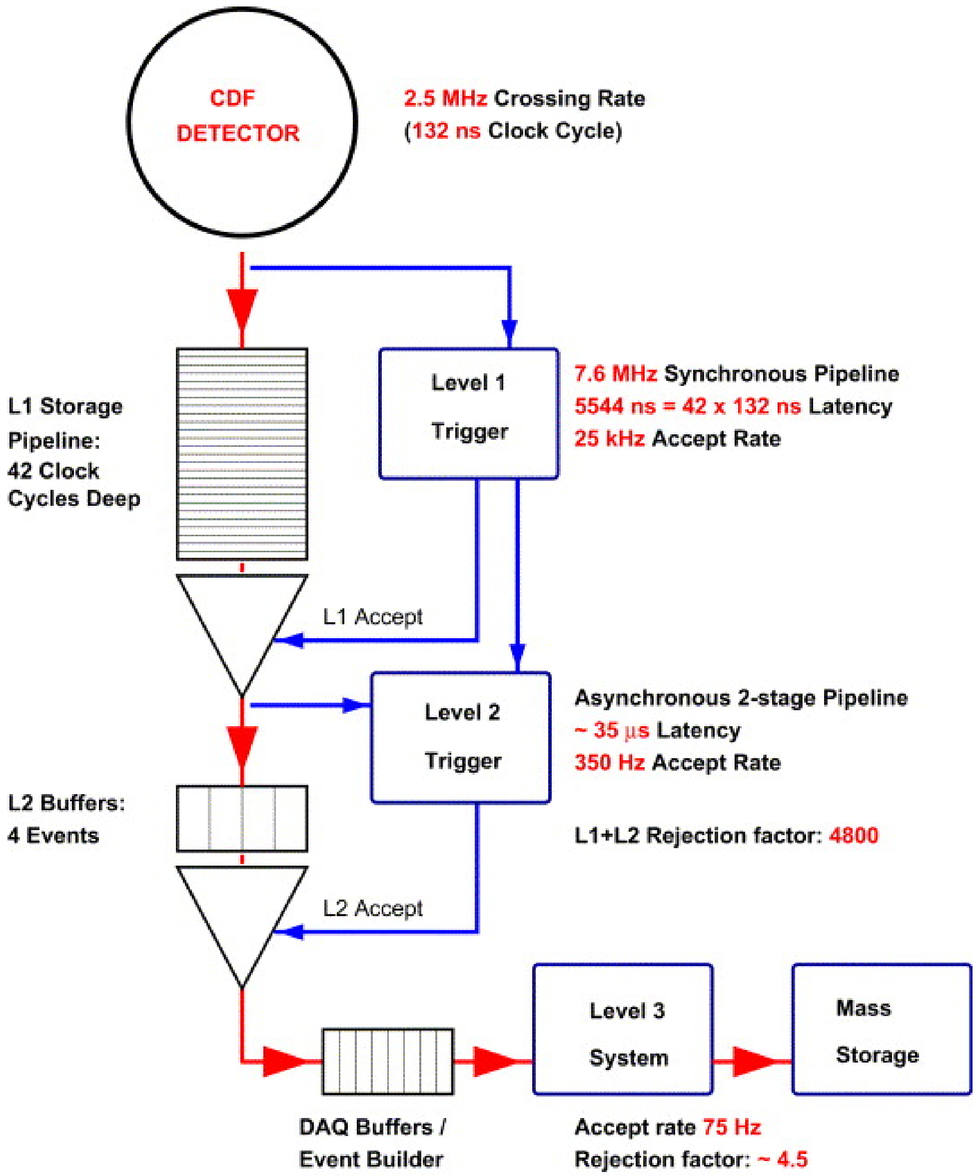

Figure 4: Block diagram of the CDF Run II Trigger System